The ESA/ESOC IGS Analysis Centre Annual Report 2001

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Introduction

This Report gives an overview of the ESOC Analysis Centre activities and a presentation of the activities during the year 2001.

This year the ESOC AC activities have continued uninterrupted and have consolidated with the timely delivery of all the products part of the IGS and participation in several of the IGS Working Groups and Pilot Projects. There have been no major changes to the routine processing during 2001 except for the inclusion in the UltraRapid product of satellite clock bias values (estimated and predicted).

Currently ESOC's GPS-TDAF (Tracking and data Analysis Facility) handles automatically the ESA ground receiver network, the IGS network data retrieval and storage and all of the routine daily and weekly data processing of the different IGS products. The system is capable of performing autonomous operations for up to about five days. Information is available on the website: http://nng.esoc.esa.de/gps/gps.html

Changes and activities in 2001

These have been the changes to IGS activities at ESOC during 2001:

Mar 2001 *Ultra-Rapid processing*: Started clock bias submissions with the UltraRapid product (24 hr estimated + 24 hr predicted).

Apr 2001 *Ultra-Rapid processing*: changed strategy from 2-step fit; RINEX data fit and then a longer arc Earth Fixed Position fit, to a 1-step fit; RINEX data and Earth Fixed Positions fitted together.

May 2001 *GLONASS processing*: Raised the allowed noise level cut-off for GLONASS data to the same level as for GPS (from 30 to 50 cycles between phase and pseudorange), this allows more data to be used in the processing at the risk of some increased noisy measurements from multipath or other causes.

May 2001 *GLONASS processing*: Started using a 9 parameter Solar Radiation Model (3 components per axis), and a 3 day RINEX data arc (from a 5 day arc).

Jun 2001 *GPS Processing*: For satellites in eclipse excluding 14 minutes of data at the exit of the eclipse (down from 30 minutes).

Dec 2001 *GPS Processing*: Changed terrestrial reference frame to ITRF2000, based on the IGS2000.SNX Sinex file generate by the IGS for the core stations.

Routine Activities

ESOC participates in the IGS as an Analysis Centre providing the following routine products either to the Analysis Centre coordinator or to the IGS Global Data Centre CDDIS:

- Final GPS Orbits plus clock biases
- Final GLONASS Orbits plus clock biases
- Rapid GPS Orbits plus clock biases
- Twice Daily Ultra-Rapid GPS Orbits plus clock biases
- Daily Rapid EOP file
- Daily Ultra-Rapid EOP file
- Weekly final EOP file
- Weekly final processing summaries
- Weekly free network solution in SINEX format
- Daily final tropospheric files
- Daily final ionospheric files in IONEX format
- Weekly combined IGS ionosphere IONEX files; ESOC is the IGS Ionosphere Associate Combination Center (IACC)
- Daily rapid RINEX clock files with 5 minutes sampling
- Daily final RINEX clock files with 5 minutes sampling

Processing Method

The ESOC GNSS precise orbit determination processes for all the cases are based on a batch least squares estimation solution of RINEX IGS station data using various numbers and distributions of stations based on availability, past performance and processing time available. The average numbers of stations used for each of the processes at ESOC are as follows:

- Final GPS POD: 52 stations
- Final GLONASS POD: 27 to 30 stations
- Rapid GPS POD: 40 to 45 stations
- Ultra-Rapid GPS POD: 25 to 30 stations

The estimation method for all the POD activities uses an in-house estimation program, BAHN, currently in version 7 and which can handle most types of data for satellite POD activities (ranges, range rates, SLR, Doris, Prare, altimetry, GNSS observables in undifferenced, and double- differenced modes). The quantities estimated by the program are variable depending on the focus of the run. For the IGS submissions the quantities estimated are:

- The station coordinates,
- The satellite state vectors,
- The solar radiation pressure extended force model parameters,

- Cycle-per-revolution empirical accelerations,
- The undifferenced carrier phase ambiguities for the ionospheric-free linear combination,
- The GPS-GLONASS receiver biases (for the GLONASS processing only),
- The Earth rotation parameters: *x* and *y* pole position and rates and Length of Day,
- The tropospheric zenith delay for every station every 2 hours,
- Station and satellite clock biases, estimated as time-dependent parameters (one value for every observation epoch).

More information on our routine GPS and GLONASS processing, processing description, model usage, result plots, etc can be found at:

`http://nng.esoc.esa.de/`
`http://igscb.jpl.nasa.gov/igscb/center/analysis/esa.acn`

Ultra-Rapid clock predictions

During 2001 the Ultra-Rapid product delivered by ESOC to the IGS started including satellite clock bias values. The Ultra-rapid product includes both estimated and predicted orbit positions every 15 minutes. The estimated part is based on the processing of two frequency RINEX data from a multitude of stations (as explained above) the prediction part is the propagation of the orbits using the estimated part as initial conditions and using very precise dynamical models.

The clock bias estimation in ESOC is based entirely on the availability of RINEX data. No accurate modelling of an atomic clock at the level of precision required is available, as there may be for the orbit, etc, and thus the estimated clock biases are always calculated from RINEX measurements. To provide clock bias values for the entire arc of the Ultra-Rapid products (estimated + predicted parts) an external clock propagation tool has been developed.

In broad terms a function is fitted to each of the satellites' clock bias values using a least-squares adjustment process. If the results of the fit are satisfactory the function is used to propagate the clock values into the future and they are then merged with the predicted positions for submission to the IGS. The function used is,

$$y_{PRN} = A_0 + A_1 t + A_2 Sin\left(A_4 t + A_5\right)$$

this function provides reasonable propagation results for 24 hours (as required in the Ultra-Rapid product), to a few nanosecond level (but still an order of magnitude worse than the estimated clocks). Figure 1 shows the clock biases estimated for two satellites (PRN 21 and 06) as the result of one of the precise orbit determination processes run at ESOC.

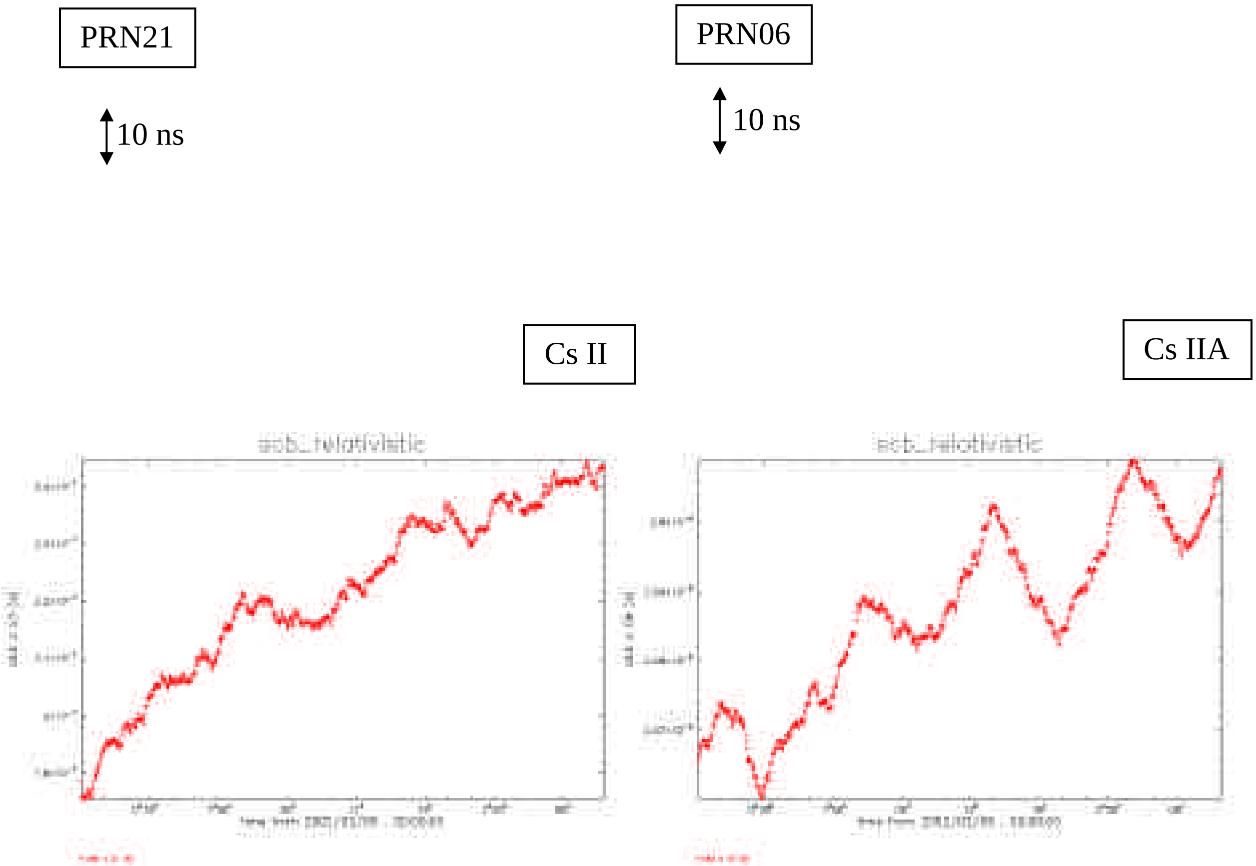


Fig. 1: Satellite clock biases estimated for 48 hrs from 12:00 Feb 6th,2002 (02037) (with the relativistic correction removed).

The function above tries to approximate the observed values (Figure 1) by adjusting the 5 parameters. Depending on how well the function can reproduce the observed values it is either used or not to propagate values in to the future. If the function cannot fit the observed values to within 10 ns then no clock value (estimated or predicted) is included in the ESOC solution. In these cases it is assumed that the estimated values may actually not be good enough for the level of precision required for the IGS. Figure 2 shows cases in which no clocks would be sent out at all since discontinuities in the satellite clock bias values (red curves), due to RINEX station data gaps or processing problems, resulted in a poor fit (worse than 10 ns) of the prediction function (green curve).

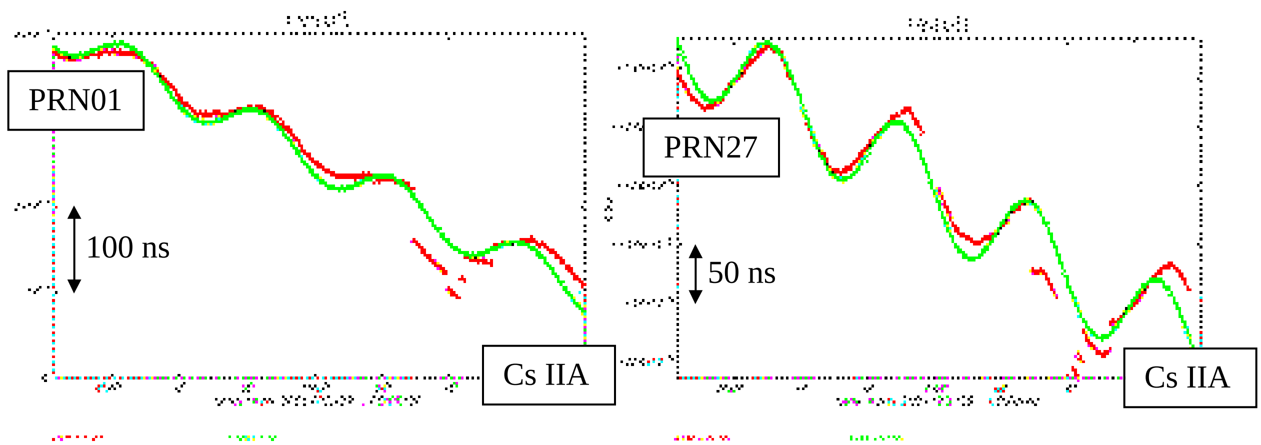


Fig. 2: Satellite clock biases estimated (red) and predicted (green) for 48 hrs from 00:00 Feb 28th,2001 (01059) (with the relativistic correction still included).

The vast majority of the time the satellite clock biases can be fitted to within 10 ns over the 48 hrs used for propagating, using the function defined above. Figure 3 shows the example of two satellites with the estimated and predicted clock bias values where the fit is OK.

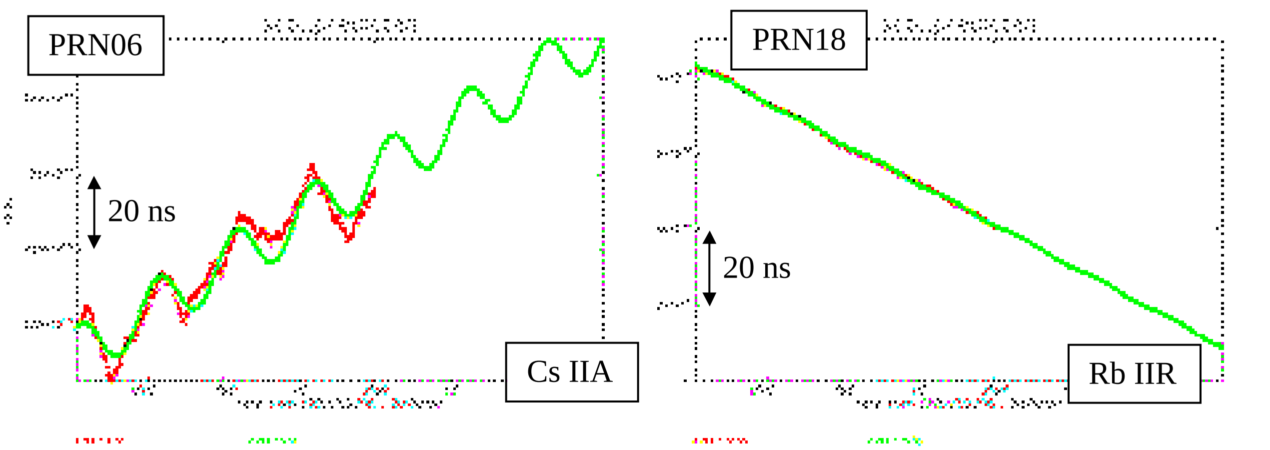


Fig. 3: Satellite clock biases estimated (red) and predicted (green) from 00:00 Feb 6th,2002 (02037) (with the relativistic correction removed).

For inclusion in the Ultra-Rapid sp3 files delivered to the IGS the clock values are merged with the orbital positions. It is clear from Figure 3 that in just joining the estimated and predicted clock bias values a jump would be seen at the transition point from estimated to predicted clocks. This discontinuity is not desired since it breaks the continuity of the Ultra-Rapid product. These jumps are also not consistent among all of the satellite clock biases, and thus are not easy to correct after the fact. Therefore at the transition point from estimated to predicted clocks the end points are matched, as shown in Figure 4.

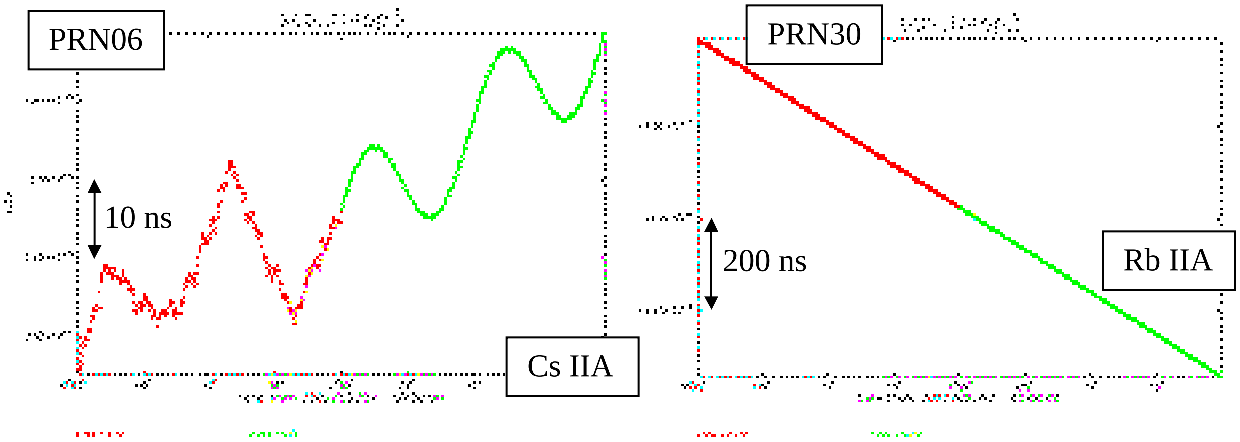
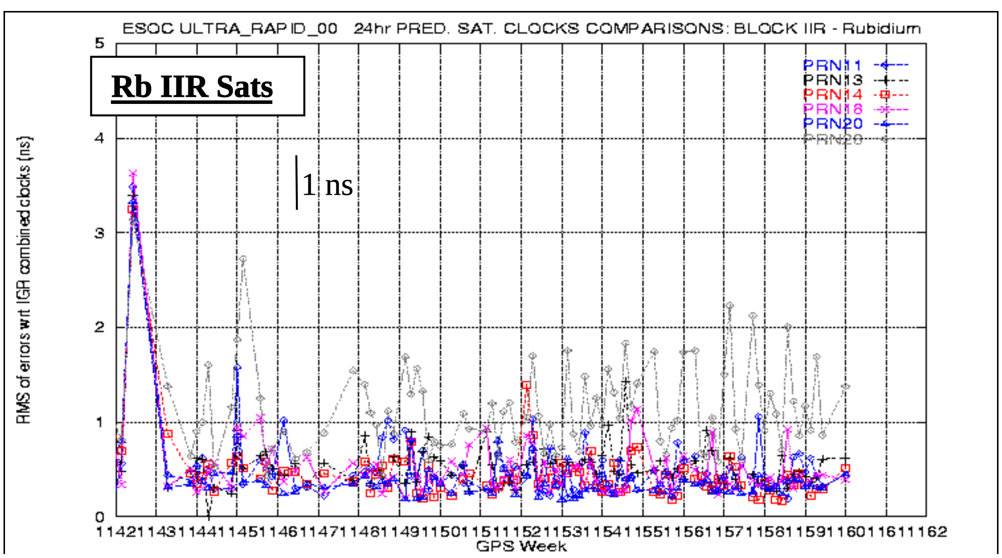


Fig. 4: Satellite clock biases estimated (red) and predicted (green) for 48 hrs from 00:00 Feb 7th, 2002 (02038) (with the relativistic correction removed).

From the Analysis Centre Coordinator (ACC) Ultra-Rapid Comparison summaries it is well known that the satellite clock bias propagations are accurate to around 5 to 7 ns (in an RMS sense over the entire constellation). Unfortunately no individual clock comparison summary is readily available except at ESOC's website:

`http://nng.esoc.esa.de/gps/igs_ana.html`

where the first 12 hrs of the predicted clocks are compared with the estimated values later obtained from the Rapid product. Figure 5 presents daily comparison results of all the satellites from two of the 4 GPS Clock/Block types combinations. The results clearly show that the ability to predict clocks into the future has mainly to do with the inherent stability of the satellite's onboard oscillator. The newer Block IIR Rb clocks are the easiest to predict since they show the best behaviour in the time scales of the Ultra-Rapid product.



Cs IIA Sats

2 ns

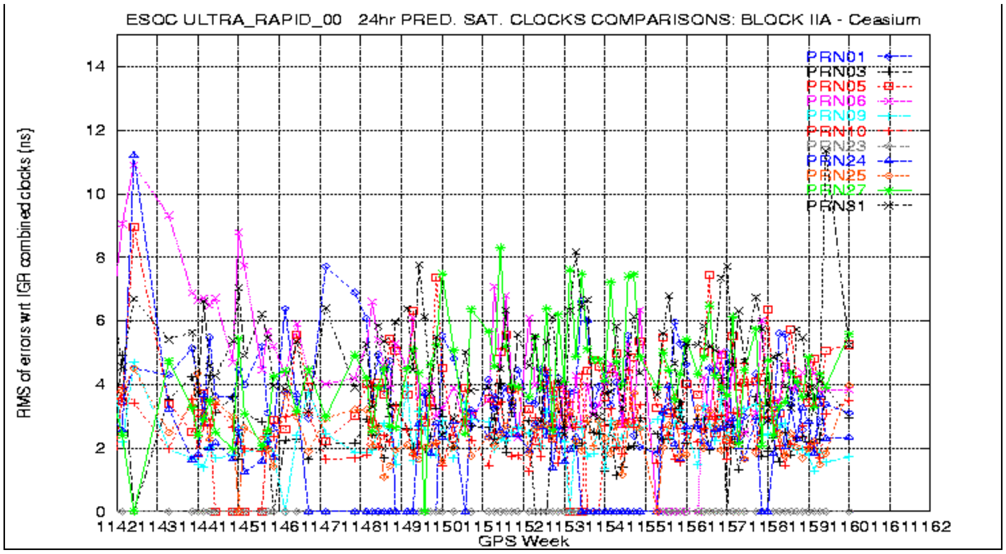


Fig. 5: Satellite by satellite comparison of predicted versus estimated clock biases from GPS week 1142 to week 1160 for two sets of GPS satellites.

Figure 5 shows the satellite by satellite comparisons of the Block IIR Rb clocks to be predictable over 12 hrs to better than a single nanosecond (except for PRN28), whereas the Block IIA Cs clocks can only be estimated to around 4 or 5 ns. Since there is no weighting currently applied by the ACC to the clock comparisons the RMS results can sometimes be very negatively affected by one bad clock prediction submission. Still on the average the clock predictions are better than the GPS navigation message by 2 or 3 ns, or around 25%.

Looking in detail at the actual clock bias values estimated and predicted, it is of interest to see Figure 6, which shows the predicted and estimated values together for two satellites. It can be concluded that given the character of the clock bias values nothing can really be gained by using more complicated fitting functions than the one above, indeed in an RMS sense estimating an offset and a drift to predict clock values is enough and that more complicated functions do not add accuracy to the clock predictions.

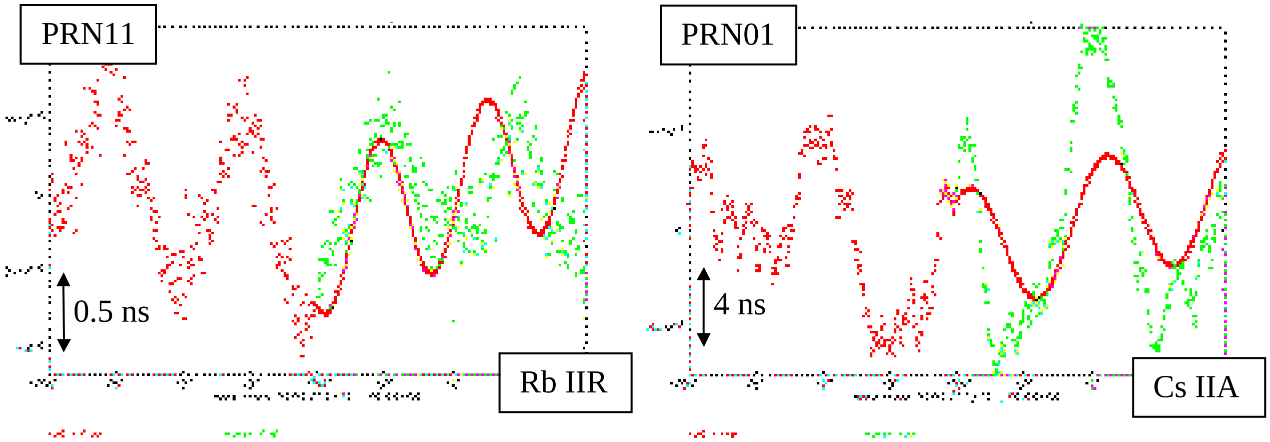


Fig. 6: Satellite clock bias values, submitted with the Ultra-Rapid (red) and estimated in the ESA Rapid process (green) for 48 hrs from 00:00 Nov. 11th 2001 (01315) (Offset and drift removed for plotting).

GLONASS Processing

GLONASS processing at ESOC has continued during 2001 under the new IGLOS Pilot Project. Some changes in the processing have been introduced and tested to try to produce more stable day-to-day solutions. ESOC's processing of GLONASS data was changed during 2001 by raising the noise cut-off permitted between the pseudorange and phase measurements from 30 cycles to 50 cycles. This in turn had the effect of increasing the amount of available data from some of the stations, which helped in the stability of the solution for those stations and in turn for the GLONASS constellation.

Another change implemented during 2001 in the GLONASS processing has been switching back to a 3-day processing arc, from a 5-day arc, which was tested from February 2000. Originally due to lack of RINEX data it was thought that increasing the daily processing arc to 5 days would allow for better parameter estimation and more stable day-to-day solutions. With the increase of RINEX data availability for GLONASS processing the data problem was improved, the processing time was also increasing considerably, so therefore the data arc was switched back to 3 days as it had been previously.

Furthermore during 2001 the processing has started estimating 4 new parameters in a 9-parameter Solar Radiation Pressure (SRP) model for the GLONASS satellites; this has been a change for testing purposes from a 5-parameter model used up to 2001 (Romero et al., 2002). The new terms which are estimated are a sine and cosine terms on the X and Y axes (Figure 7).

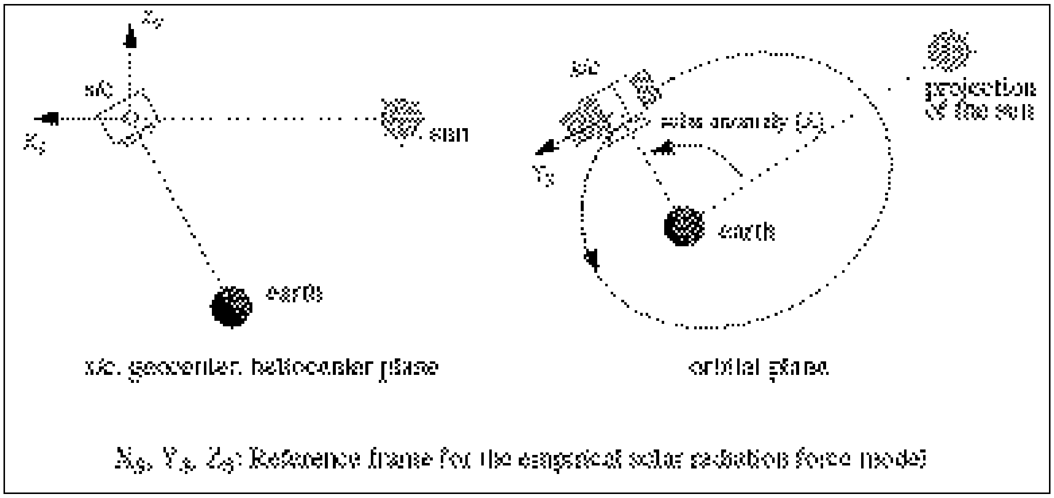


Fig. 7: GLONASS Solar Radiation Pressure Modelling.

During 2001 the GLONASS constellation of satellites has continued to decrease in numbers. Even with the launch of three new satellites in December 2001 (two of which were later introduced during 2002), the number of satellites being decommissioned meant that the total number of active dual-frequency satellites by the time of this writing was only seven, plus one which is yet to be introduced officially (number 711, slot 5) but which has been transmitting some data. At the same time the IGEX station network has continued to increase, which has made for more stable day to day solutions for each of the remaining satellites, as more data is available.

The GLONASS orbit processing at ESOC currently only processes dual frequency dual system receivers, mainly Topcon and Ashtech Z18 receivers. During 2001 the increasing number of stations meant that overall the useful GPS/GLONASS stations have increased to between 30 to 35 stations. The problem continues to be poor world coverage with most stations concentrated in Europe as can be seen from Figure 8, below. In this figure the stations in capital letters are GPS-only stations which are part of the IGS ITRF core and which are kept fixed, the lower case stations are the ones with GPS/GLONASS dual frequency receivers, the stations in bold are the ones actually selected for this run.

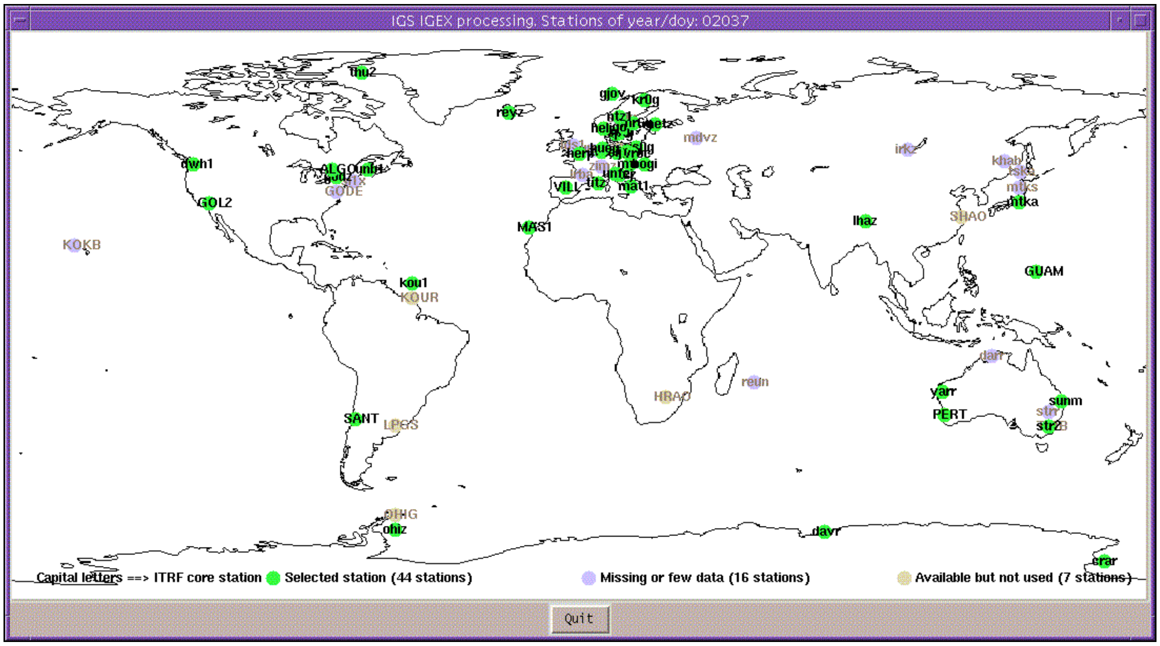


Fig. 8: GPS/GLONASS typical station selection for IGLOS processing.

Figure 9 shows the orbit comparisons between the solutions from CODE, BKG, MCC (Control Centre Moscow) and ESOC versus the GLONASS combination up to the time of writing. CODE orbit contributions ceased during 2000. The ESOC comparison to the combination has stabilised at an error level of around 20 cm. The general degradation of the comparison results observed in the plot during 2001 was most likely the result of bad solutions provided by ESOC, for GLONASS satellite 784, in slot 8. Once this solution was systematically excluded from the ESOC submission the comparison results of all the Centres improved to the expected sub-20 cm level.

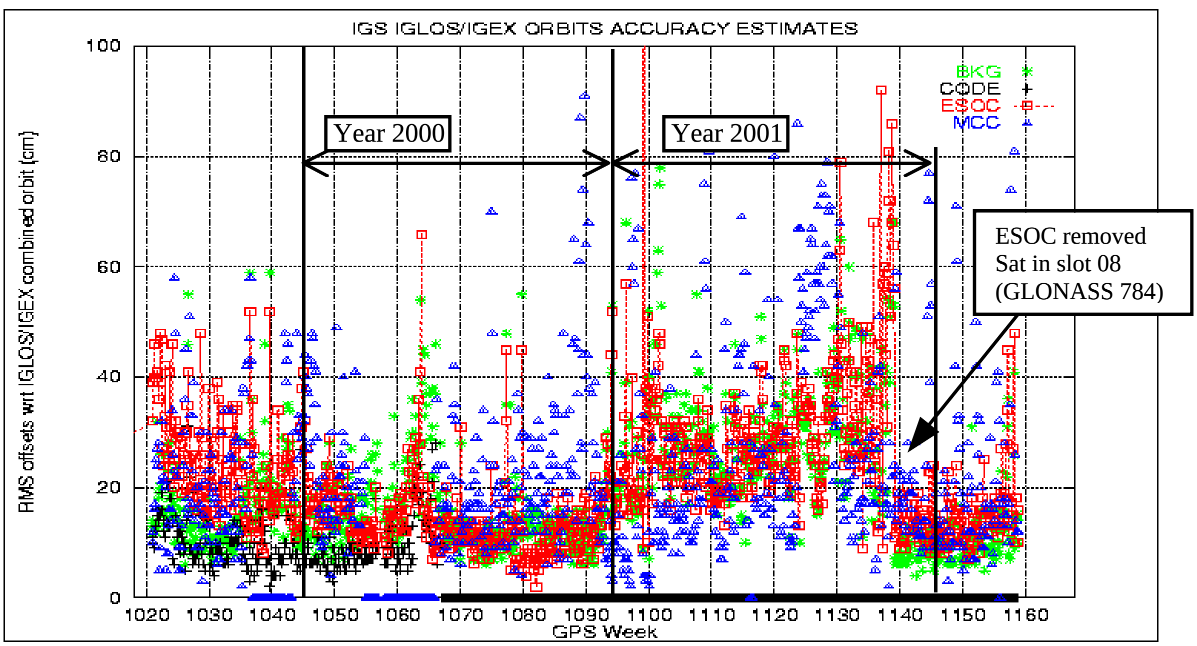


Fig. 9: IGLOS/IGEX AC orbit comparisons versus the combination.

Figure 9 and the problems with satellite 784 experienced by ESOC are indicative of the urgent need of adding Analysis Centres to the GLONASS orbit processing. With only two microwave-based orbit solutions (BKG and ESOC) for the entire set of active satellites it is impossible for the ACC to exclude bad satellites since there can be no majority voting as there is in the GPS combination process. Unfortunately the MCC solution only includes three satellites (the ones tracked by SLR) so it serves only as a limited external check for each week's combination process.

On improving the availability and world coverage of GPS/GLONASS data ESOC has purchased and installed a Topcon (formerly Javad) GPS+GLONASS receiver at our permanent station in Kourou (French Guyana), which was tested and started supplying some dual system data during 2001, both for IGS and IGLOS activities. The station has the identifier KOU1 and it is connected to the external Cesium reference clock at the station as is our other station KOUR.

Ionosphere Processing

Routine processing of ionospheric Total Electron Content (TEC) maps and satellite/receiver differential code biases (DCBs) continued during 2001.

The ionosphere processing in final mode continued with the rapid orbits. The number of ground stations used could be increased to about 180. The 24 hours time resolution with which the TEC maps are produced, could not be increased in 2001. The daily routine ionosphere processing in 2001 was as follows:

1) A nighttime TEC data fit is made to obtain a set of reference DCB values for that day. The nighttime TEC itself is absorbed in this fit with low degree and order spherical harmonic. In the other fits 2) - 4) these DCBs are then introduced as constraints.
2) A Chapman profile model is fitted to the TEC data of that day, where the layer of maximum electron density N0 and its height h0 are estimated as surface functions of geomagnetic latitude and local time. h0 is restricted to have values within a predefined range only, currently 350 km =< h0 =< 450 km or 400 km =< h0 =< 450 km (Figure 10). This run is the official ESOC contribution to the IGS Ionosphere Working Group to be part of the combination.
3) A Chapman profile model is fitted to the TEC data, where h0 is estimated as a global constant. This run is made for test reasons and theoretical studies.
4) A Chapman profile model is fitted to the TEC data, where h0 is kept fixed as global constant at a height of 450 km, and the influence of the solar zenith angle is not accounted for. This run is made for test reasons and theoretical studies.

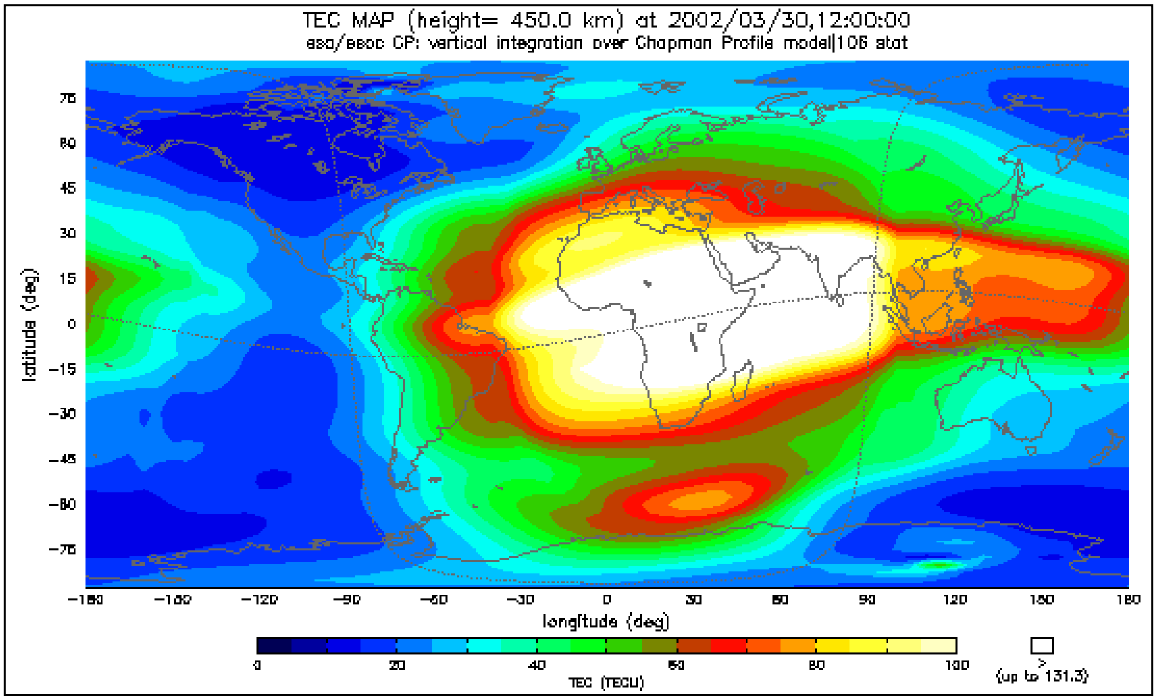


Fig 10: Global TEC map obtained from a fit of type 2) for 30/03/2002 using 108 stations.

Beyond the routine processing of our own TEC maps, ESOC has also chaired the IGS Ionosphere Working Group (Iono_WG) during 2001 (Feltens, 2002). As part of these activities, ESOC has been responsible for the weekly comparisons of Iono_WG products as IGS Ionosphere Associate Combination Centre, and generally for the coordination of the activities of this working group. (Feltens,)

LEO Activities

In the Potsdam Meeting of February 2001, ESOC offered to act as Associate Analysis Centre Coordinator for the IGS LEO Pilot project and took up this role in May (Boomkamp, 2002). The first substantial set of LEO GPS data was also released in May 2001, allowing for an increase in analysis activities at the IGS Associate Analysis Centres.

During the summer it became clear that the processing of the CHAMP data was not straightforward, and many centres seemed to come across similar practical problems. In response to a request from IGS LEO, GFZ organized a CHAMP user meeting in October, which was attended by representatives of most European groups, and was well received. A collection of practical recommendations that emerged during this meeting has been collected on some pages on the ESOC website dedicated to IGS LEO.

Shortly after the User meeting, the CHAMP Orbit Comparison Campaign was launched and coordinated by ESOC. Initial results of this campaign show that the interest in this kind of activity is substantial, and that it can support analysis activities in many different ways.

Future Activities

ESOC Analysis Centre will remain active during the next year, continue the regular contributions to the IGS orbit and clock products, troposphere, ionosphere, station network solutions and EOPs. The processes will be streamlined and the GPS-TDAF will be improved for more efficient and independent operations.

In the area of ionosphere estimation the following major improvements are under preparation:

1) The time resolution of ESA TEC maps shall be enhanced from currently 24 hours to at least 2 hours. Also the RMS maps shall be included into the daily ESA IONEX files. The required mathematical algorithms were worked out and are currently (autumn 2002) in the process of implementation into the ESA IONMON software.
2) The mathematical representation of the ionosphere as one Chapman layer, of which the maximum electron density and the height of maximum electron density are estimated as surface functions, will be replaced by a multi-layer model: The ionosphere will be represented as a superimposition of several layers, e.g. E, F_1, F_2, each of which will be modelled as a Chapman profile or by an empirical profile function. Some of these layers will depend on the solar zenith angle, while others will not. Champ electron density profiles derived from GPS occultation data will be introduced as additional observables to the TEC observations derived from dual-frequency GPS data. The mathematical algorithms for this extended ionosphere modelling have been worked out and coded. At the time of submission (autumn 2002) the new subroutines are in the tests and validation phase.

For LEO processing:

From the lessons learned with CHAMP analysis, it has become clear that the normal GPS processing software at ESOC has notable shortcomings in the processing of LEO data. Particular problems are the computation of the LEO clocks and the handling of phase data. The precision levels of ESOC POD products for LEO will not drop below the ~20 cm level until the phase data is correctly included in the processing.

To meet these challenges, ESOC will start a project in 2002 to implement GPS data processing in the NAPEOS software, a package that by its internal structure solves many problems that are currently preventing more precise LEO results. In addition, preparation of other LEO missions will take place, in particular for JASON. With its higher orbit and similarity to the TOPEX/Poseidon mission, JASON is expected to offer less practical difficulties in the processing of its GPS data than CHAMP and GRACE, so that its data must be regarded as an important basis for assessing the contributions that LEO data could bring to IGS processing.

References

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